CHAPTER 22

ELECTROMAGNETIC INDUCTION (PART 1)

The force and torque exerted on a current carrying conductor as it crosses a magnetic field is utilised in many types of electrical equipment and machinery. In this Chapter the power generated in current carrying conductors which are free to rotate 360^{o} around a fixed or pivot point, while at the same time cutting a stationary magnetic field, is examined. The principles involved are used in the operation of electric motors and generators, a further study of which is made in stage 2 of the course.

22.1 INDUCED e.m.f.

When a conductor is moved through a stationary magnetic field so that it cuts or intersects the lines of force of that magnetic field, an e.m.f. is induced in the conductor. Similarly, if the lines of force of a moving magnetic field cut across a stationary conductor, an e.m.f. will be induced in the conductor (Figure 22.1).

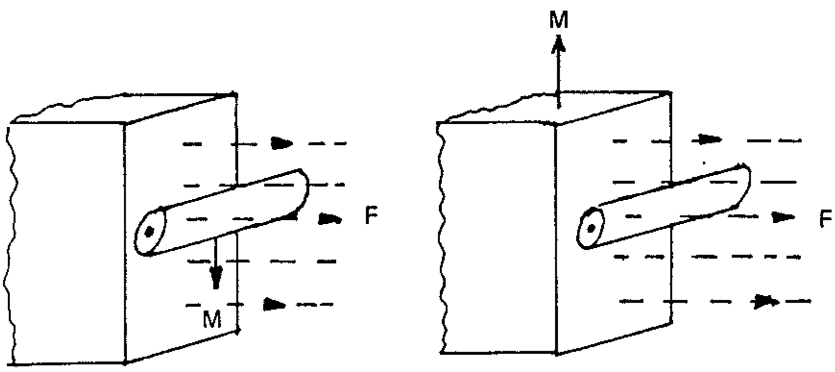

Figure 22.1

Faraday's Law of electromagnetic induction states -

When relative motion exists between a conductor and a magnetic field, such that the conductor cuts the magnetic field, an e.m.f. is induced in the conductor. The magnitude of the induced e.m.f. depends upon three factors.

(a) The strength of the magnetic field or more accurately the flux density of the field. Increasing the flux density increases the number of lines that can be cut by the conductor resulting in an increased e.m.f.

(b) The length of the conductor. By the length of the conductor it is meant that length which is cutting the lines of force of the field, or what is known as the 'effective length'. In figure 22.2(a) the effective length is less than the width of the magnet, while in figure 22.2(b) the effective length is the same as the width of the magnetic field. The conductor in figure 22.2(c) is longer than the width of the magnetic field but the effective length remains the same as that in figure 22.2(b).

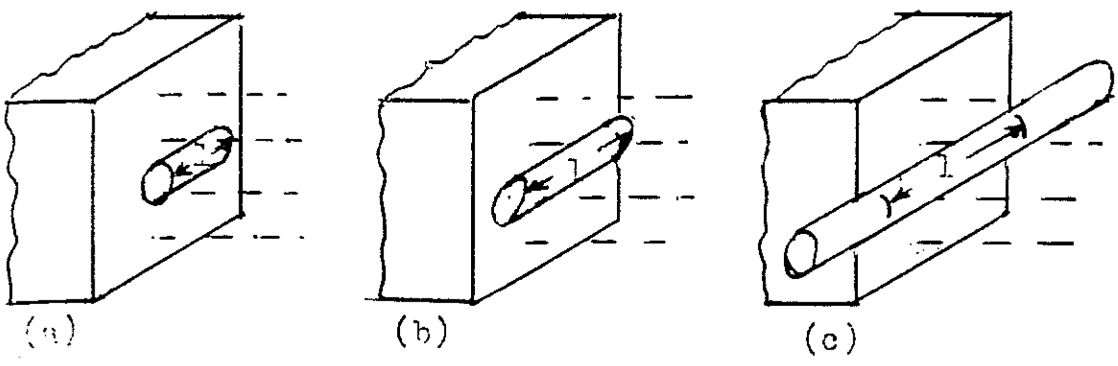

Figure 22.2

Increasing the effective length is the same as increasing the lines of force cutting the conductor, therefore, an increase in effective length would result in a increase in induced e.m.f.

The third factor influencing the magnitude of the induced e.m.f. is the rate or velocity that the conductor intersects the magnetic field. When the conductor is stationary in the magnetic field, zero induced e.m.f. occurs. Moving the conductor slowly through the field causes an induced e.m.f. in the conductor. Increasing the speed at which the field is cut increases the effect of the lines of force on the conductor electrons further increasing the magnitude of the induced e.m.f. From this observation it can be seen that an increase in the rate (velocity) at which the field is cut results in an increased induced e.m.f.

Combining all three factors for induced e.m.f. gives –

$$e = B \ell v$$

Where -

e = induced e.m.f. in volts

B = flux density in tesla

ℓ = length of conductor in metres

v = velocity of conductor in metres per second

Example 22.1

A conductor, 250 millimetres in length, intersects a magnetic field whose flux density is 1.2 tesla, at a velocity of 2 metres per second. Calculate the e.m.f. induced in the conductor.

$B = 1.2 \text{ T}$

$\ell = 250 \times 10^{-3} \text{ m}$

$v = 2 \text{ ms}^{-1}$

$e = ? \text{ V}$

$e = B \ell v$

$= 1.2 \times 150 \times 10^{-3} \times 2$

$= 0.6 \text{ V}$

22.2 ELECTRICAL MACHINERY

Direct current electrical machinery consists of two basic sections, each of which carry conductors. One of the sections is stationary while the other rotates by means of a shaft supported to each end of the stationary section. In the d.c. machine, the stationary section comprises windings which set up a magnetic field, similar to that of two bar magnets, while current is passing through the windings. (Figure 22.3).

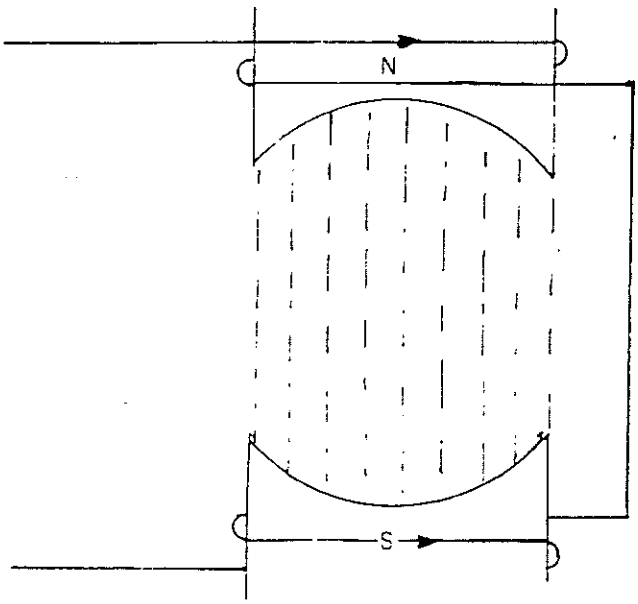

Figure 22.3

The conductors on the rotating section are located in slots below the outer surface of the rotating section. (Figure 22.4).

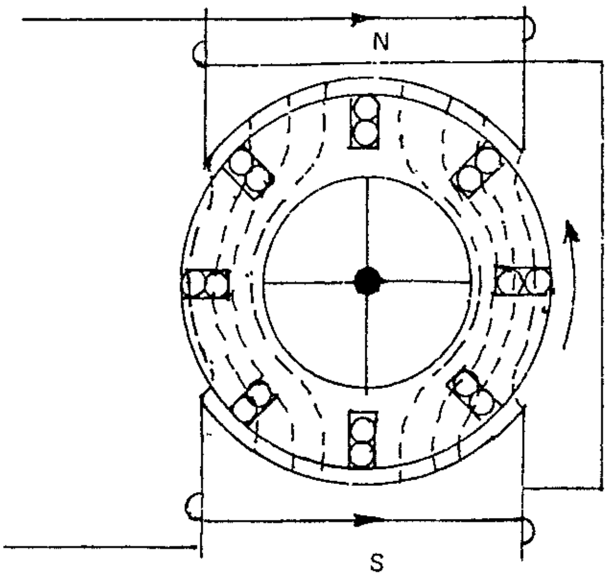

Figure 22.4

The conductors are connected to a device called a commutator and current is fed into or delivered from the rotating section by the means of carbon brushes. (Figure 22.5).

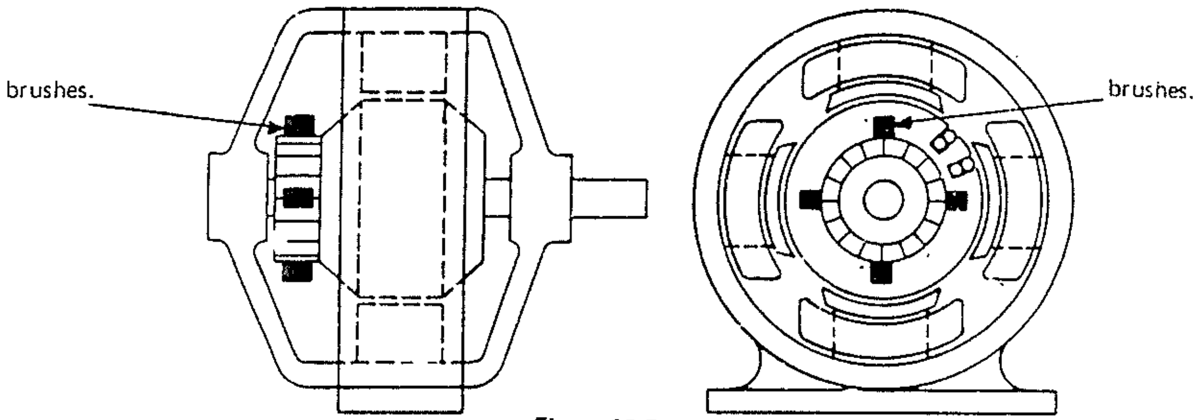

Figure 22.5

If power is delivered by the machine it is known as a generator but if power is supplied to the machine it is known as a motor.

The operation of electrical machinery relies on the relationship between magnetic field direction, the relative motion of the conductor, and the direction of the induced e.m.f., or the current in the conductor. Fleming's Right-Hand rule gives the relationship for generated e.m.f. while his Left-Hand rule give the relationship for motor action.

22.3 FLEMING'S RIGHT AND LEFT HAND RULES

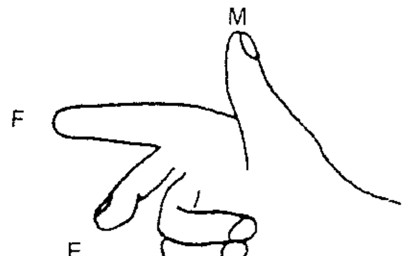

Figure 22.6

Right hand rule for generated e.m.f.

The rule states that if the right hand is held as in Figure 22.6 with the thumb pointed in the relative direction of the motion of the conductor, and the forefinger pointed in the direction of the lines of force, then the second finger will indicate the direction of the induced e.m.f.

The Left-Hand rule states that the left hand should be held as in Figure 22.7.

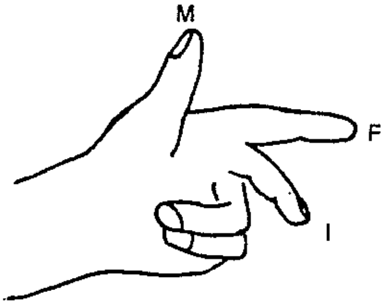

Figure 22.7

Left hand rule for motor action.

The forefinger points in the direction of the lines of force, the second finger points in the direction of the current in the conductor while the thumb indicates the direction the conductor would move if free to do so.

22.4 POWER IN d.c. MACHINES

Electrical machines are energy converters. A generator converts the mechanical energy of the drive motor or prime mover into electrical energy. An electric motor converts electrical energy into mechanical energy. Because each conversion occurs over a period of time mechanical and electrical power are also involved. In an electrical system -

Current will flow in a conductor while a difference of potential 'e' exists between the ends of the conductor Therefore, there must be power consumed or generated in the conductor. From previous work -

$P = E\ I$

$= e\ i$ (for instantaneous values)

But —

$e = B\ \ell\ v$

substituting for 'e' in the power equation gives —

$P = B\ \ell\ v\ i$

Where —

P = power in watts

B = flux density in tesla

v = velocity of conductor in metres per second

i = current in the conductor

ℓ = length of conductor cutting the magnetic field

Example 22.2

A conductor, 500 millimetres in length, intersects a mangetic field, whose flux density is 1.5 tesla, at a velocity of 10 metres per second. Calculate the power developed in the conductor when there is 5 amperes in the conductor.

$B = 1.5\ T$

$\ell = 500 \times 10^{-3}\ m$

$v = 10\ ms^{-1}$

$i = 5\ A$

$P = ?\ W$

$P = B\ \ell\ v\ i$

$= 1.5 \times 500 \times 10^{-3} \times 10 \times 5$

$= 37.5\ W$

Example 22.3

Calculate the velocity of a conductor 500 mm in length and carrying 10 amperes if it consumes 30 W of power as it passes through a field of 0.75 tesla.

$\ell = 500 \times 10^{-3}\ m$

$i = 10\ A$

$B = 0.75\ T$

$P = 30\ W$

$v = ms^{-1}$

$$P = B \ell v i$$

$$v = \frac{P}{B \ell i}$$

$$= \frac{30}{0.75 \times 500 \times 10^{-3} \times 10}$$

$$= 8\ ms^{-1}$$

The electrical power (e i) supplied to a conductor is converted into mechanical power. This mechanical power forces the conductor to move out of the influence of the magnetic field. However, as one conductor moves out of the field another current carrying conductor moves into the field and the same reactions occur. This results in a continuous movement of conductors rotating the shaft of the machine, the basis for conversion of electrical energy to mechanical energy.

Equations in this chapter

(1) $e = B \ell v$

(2) $P = B \ell v i$

TUTORIALS 1.22

(1) A conductor which is moving at a velocity of 2.5 ms^{-1} and is 500 mm in length, intersects a magnetic field whose density is 0.125 tesla. Calculate the e.m.f. induced into the conductor.

(2) A conductor carrying 10 amperes and 750 mm in length cuts across a magnetic field whose strength is 0.25 tesla at a velocity of 2 metres per second. Calculate the power consumed by the conductor.

(3) A conductor moving through a magnetic field of 1 tesla at a velocity of 5 metres per second has an e.m.f. of 1.5 volts induced into it. Calculate the length of the conductor.

(4) A 100 mm long conductor carrying 10 amperes cuts a magnetic field of 0.5 tesla at a velocity of 5 metres per second. Calculate the power developed in the conductor.

(5) Calculate the e.m.f. induced into a conductor 300 mm in length as it crosses a magnetic field of 1.25 tesla at a velocity of 7.5 metres per second.